STATIC AND DYNAMIC ANALYSIS OF STIFFENED PLATE USED IN MACHINE TOOL COLUMN

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ABSTRACT

Static behavior (under torsion and bending loading) of machine tool column was studied in this paper. The effects of changing the cross sectional area of the column itself on the deformations (design parameters) was investigated. The adding of stiffeners and changing the stiffeners cross sectional area are also verified. The results show that using of stiffeners can produse a great reduction in deformation of the column structure under the stastic loading mentioned above. Also using stiffeners with different cross-sectional areas suggest the best stiffener cross-sectional shape can be used to give the minimum deformations of column structure. Dynamic analysis of column involves calculating natural frequencies and mode of different column structure mentioned above, these frequencies are fairly insensitive of adding stiffeners to colmn structures.

KEYWORDS

Static analysis, Dynamic analysis, Stiffened Pplates, Machine Tool Column, Natural Frequencies

الخلاصة:

تم في هدا البحث دراسة التصرف الستاتيكي (تحت حمل الالتواء والانحناء) لهيكل عمود ماكنة تشغيل ميكانيكي. حيث تم دراسة تاثير تغيير شكل المساحة المقطعية للعمود للتشوهات (عنصر التصميم). كما تم دراسة تاثير اضافة دعامات لهيكل العمود وكدلك التحقق من تاثير تغيير المساحة المقطعية لهده الدعامات.تبين النتائج ان اضافة الدعامات يمكن ان ينتج تقليل كبير في تشوهات العمود تحت تأثير الاحمال الستاتيكية المدكورة كدلك استخدم دعامات بمساحات مقطعية مختلفة يقترح اعطاء افضل شكل الدي يعطي اقل تشوه لهيكل العمود.التحليل الديناميكي للعمود تضمن قياس التردد الطبيعي لهياكل العمود المختلفة المدكورة اعلاه ، وقد تبين ان هده الترددات تتأثر قليلاً بأضافة الدعامات لهيكل العمود .

NTRODUCTION:

Stiffened plates are structural component consisting of plate reinforced by a system of ribs to enhance their load-carring capacity. These structural components have been widely applied to aircraft, ships, bridges, buildings, rockets and machine tool structures as well as in many other branches of structural engineering. Thus, there are many circumstances in which stiffened plate structure is exposed to static and dynamic load. Different approaches have been suggested for static and vibration analysis of stiffened plates, **(Rossow and Ibrahinkhail 1978)** applied the constraint method to the finite element static analysis of concentrically and eccentrically stiffened plates, the displacement fields in the stiffener are expressed in term of the displacements of the middle surface of the plate.

Supposing the strain energy of plate and stiffener, the stiffness matrix of compound structure is obtained, for arbitrary order of approximating polynomials. **(Mokhopadhyay 1981)** suggested a new approach to account for the stiffeners within the plate element under plane stress. It caters accurately the spacing and orientation of the stiffeners, the results of stiffened deep beams, a rectangular ship plating and typical web frame of tanker obtained by using this new approache. **(Deb and Booton 1988)** used linear finite element models based on Mindlins shear distortion theory for bending of eccentrically stiffened plates subjected to transverse loading. Two models using discrete plate-beam formulation are given superiority of one over the other discussed, also additional formulation applicable to technically orthotropic plate under distributed lodaing is included. **(Palani et al 1992)** proposed isoperimetric finite element models, the eight – noded and nine-noded models have been arrived at by appropiatly combining Lagrangian plate shell elements with three node isoperimetric beam element. **(Omurtag and Akoz 1992)** presented a new functional for thin cylindrical shells and space bars with geometric and dynamics boundary conditions, using Gateaux diffrentials. **(Rao et al 1993)** applied a finite element analysis of the large deflection behavior of stiffened plates using isoperimetric quadratic stiffened bending element. The evaluation of fundemental equations of stiffened plates is based on Von Kerman s theory. **(Singh and Miller 1992)** deal with the design analysis of a twin head horizontal press using finite element model, developed for the press, quantitative results useful to press designers. Some suggestions are made to improve the stiffness and torsion rigidity of the press. In modeling the twin head horizontal hydrualic press, different elements types are used, rectangular, quadrilateral, traingular, beam and 8-node solid element. The entire model possesses 4542 degree of freedom. In present work finite element approach is applied to analyze the static and dynamic behavior of stiffened plates for analysis of machine tool column.

MODELING OF THE COLUMN:

Software Nastran(70.7) and Patran(90) are used in analyzing the machine tool column, through the following steps:

1. Geomatry modeling.
2. Solution.
3. Getting the results.

The (3D) column structure is modeled using shell (elastic shell) element with both bending and membrane capabilities **Fig.1-a**. The element has both bending and membrane capabilities, both in-plane and transverse loads are permitted and six degree of freedom, translation in the nodal X,Y,Z directions and rotation about nodal X,Y,Z axes.

While stiffeners of this column are modeled using beam (1-D elastic beam) element. This beam is uniaxial element with tension, compression, bending and torsion capabilities. The element has two degree of freedom at each node, translation in X axis and rotation about Y axis, **Fig.1-b**. The element position is defined by offsetting from the column structure shell.

Solution steps consist of applying the boundary conditions (the column modeled as cantilever), setting the load (6kNm for bending or torsion) and solve the eq.(1) to get the displacement which is the most impotrant design variable for the column, while obtaining the natural frequencies of this column is done by solving eq.(2):

$$[K] \times \{U\} = \{F\} \qquad (1)$$

$$([K] - \omega^2[M])\{U\} = 0 \qquad (2)$$

RESULTS AND DISCUSSIONS:

Comparison of Results:

For verification, simply supported steel square stiffened plate (Dep and Booton 1988) is modeled under a uniform distributed load with (4+4) orthogonally placed stiffeners of rectangular section, the obtained result for max. deflection is (2.921E-3) and gives good agreement with the published result (3.365E-3) in meter.

Stiffened Column:

The column structure of machine tool has been verified for different cases to study the effects of some design variables on the static behavior of that structure.

Machining forces, which are transmitted to column structure by the slides causing torsion and bending of the column, can be calculated as shown below (Sen and Bhattacharyya 1975):

$$F_x = (C_p) \times (K_p) \times (K_B) \times (d^{xp}) \times (S^{yp}) \qquad (3)$$

$$M_T = (C_m) \times (K_p) \times (K_B) \times (d^{xm}) \times (S^{ym}) \qquad (4)$$

$$F_y = M_T \times \left({}^{2}/_{d}\right) \quad (5)$$

$$T = F_y \times X \quad (6)$$

$$M_B = F_x \times Z \quad (7)$$

$$F_T = \left({}^{T}/_{Y}\right) \quad (8)$$

$$^{F_B}/_{2} = M_B/Z \quad (9)$$

The first design variable is changing the cross-sectional area of the column as in **Fig.2-a**, the cross-sectional area and material properties of each structures are given in **Table 1**, these three column structure are analyzed under bending and torsion loading as shown in **Fig.2-b**, the deformations results of these structures are compared in **Table 2** and plotted against the length of the column in **Fig.3** in which column with square section has minimum deformations.

The second variable is adding of orthogonal stiffeners (12 vertical stiffeners and 10 rings spaced equally) to the three column mentioned above, also the effect of this parameter on the deformation of these structures under the two static loading types are compared in **Table 2** and shown in **Fig.4,5** and **6**.

The third parameter is changing the cross-sectional area of the orthogonal stiffeners which are added to the three column structure as mentioned above, the cross-sectional area and material specifications of each beam type are given in **Table 1**. Studying the effects of this variable is shown in **Table 2** and **Figs. 4, 5** and **6** in which column stiffened with I- section beams has the minimum deformations.

Knowledge of natural frequencies and modes is important from a design viewpoint to avoid resonance conditions and it is also the foundation for forced response calculations. The natural frequencies of this column with different cross-sectional area and with stiffeners are obtained in **Table 3**, while the first mode of different cross-section area without stiffeners are shown in **Fig.7**.

CONCLUTIONS:

It is apparent from the obtained results that the best cross-sectional area of the column structure without stiffeners is the square shape which gives a reduction of 62.685% in deformation of the column under bending loading, also under torsion loading it gives 66.885% reduction of the deformation (compared with maximum deformation for both cases).

Adding the stiffeners to the column structure improve the static behavior of the column, the best reduction in deformation of the structure is done with a beam of I cross-sectional area which gives 72.224% reduction of deformation (with column of square section) under bending load and 91% reduction of deformation (with column of circular section) under torsion loading (compared with maximum deformation in both cases), while adding of these stiffeners have a little effect on the natural frequencies of different column structures because these structures are stiff and heavy.

Table 1: Geometry and material properties of column and its stiffeners.

Column				Stiffeners		
Cross-Section	**Square**	**Circular**	**Hexagonal**	**I section**	**Rectangular**	**Circular**
Area(mm^2)	**47760**	**47752.208**	**47814.3595**	**1386**	**1386**	**1386**
E(GN/m^2),v	**210 .3**	**210 .3**	**210 .3**	**210**	**210**	**210**

Table 2: Column max. displacement component(mm).

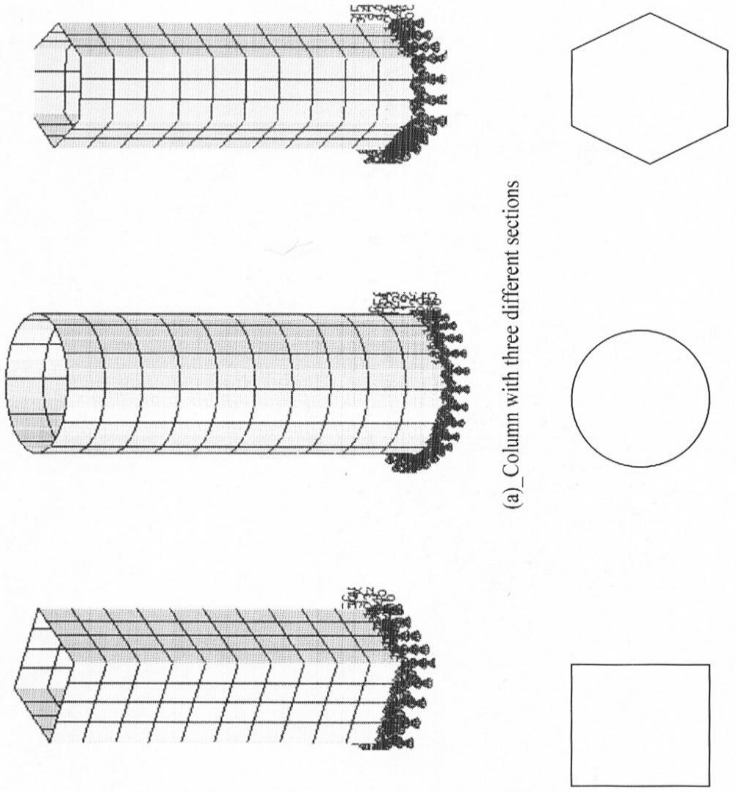
Stiffeners type	Bending Load			Torsion Load		
	Square column	Circular column	Hexagonal column	Square column	Circular column	Hexagonal column
Without stiff.	.072315	.143215	.1938	.161357	.283126	.487274
I-section	.053829	.055092	.088833	.071935	.043848	.13738
Rect.	.056879	.062494	.102152	.08853	.07373	.181651
Circ.	.059229	.069587	.113294	.098704	.10092	.223053

Table 3: Natural frequencies (Hz) for column.

Mode no.	Square column				Circular column				Hexagonal column			
	Without stiff.	I-section	Circ.	Rect.	Without stiff.	I-section	Circ.	Rect.	Without stiff.	I-section	Circ.	Rect.
1	125.6	91.7	100.5	94.2	118.8	82	89.1	85.5	134.2	91.2	93.9	92.6
2	125.6	91.7	100.5	94.2	118.8	82	89.1	85.5	134.2	91.2	93.9	92.6
3	133.3	100	109.3	102.6	162.5	118.7	130.1	125.2	140.4	105.3	109.5	108.1
4	133.3	100	109.3	102.6	162.5	118.7	130.1	125.2	140.4	105.3	109.5	108.1
5	157.4	125.9	133.7	130.6	260.9	208.7	216.5	206.1	300.9	240.7	252.7	246.7

a)-Quad 4 (b)-Bar2

(Fig. 1: Element type that used in modeling the column structure.



(a)_Column with three different sections

(b)_ Top view of column structure

Fig. 2: F.E. model of column structure

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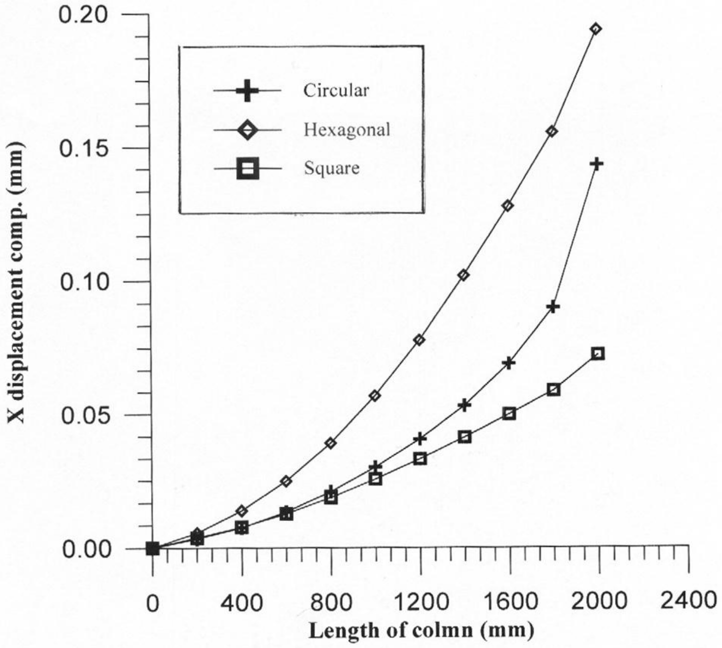
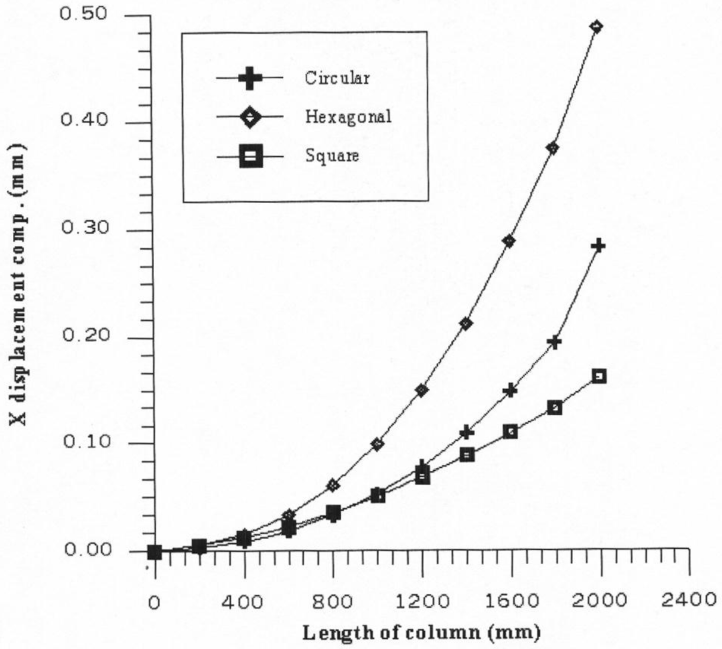


(a)_Bending load



(b)_Torsion load

Fig.3 : Max. displacement of column with different cross-section

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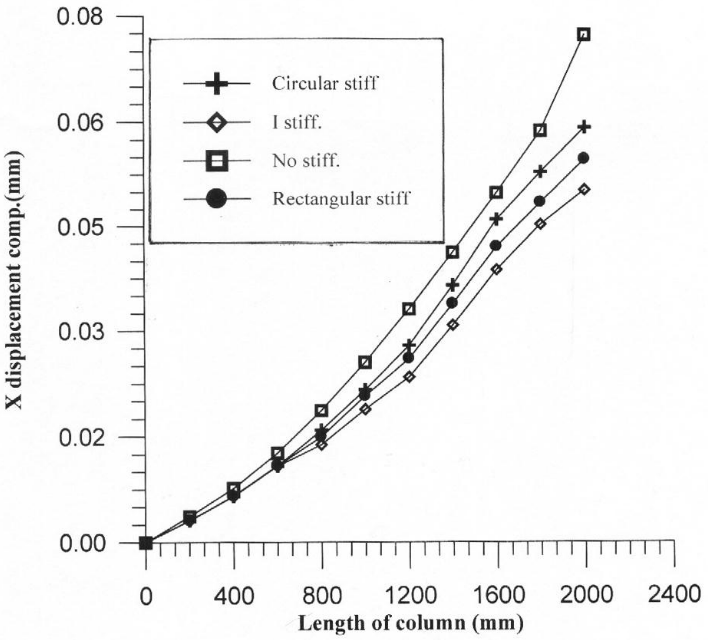
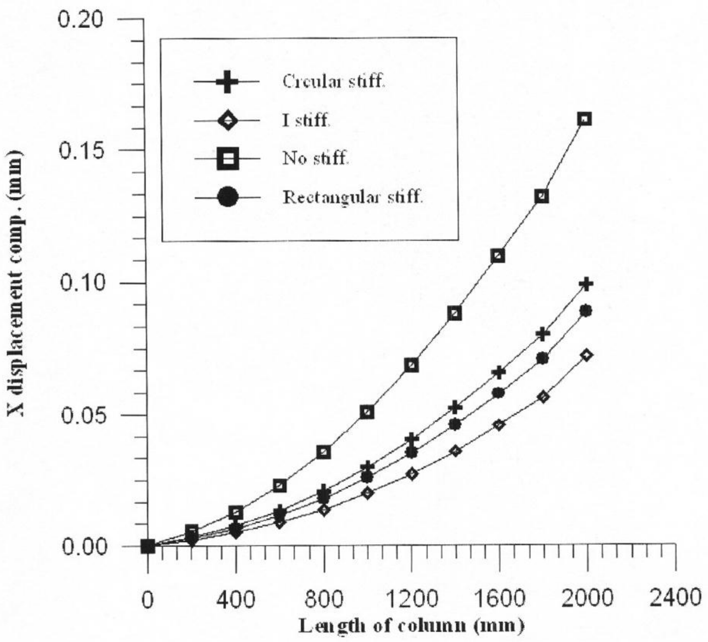


(a)_Bending load



(b)_Torsion load

Fig.4 : Max. displacement of column with square cross-section

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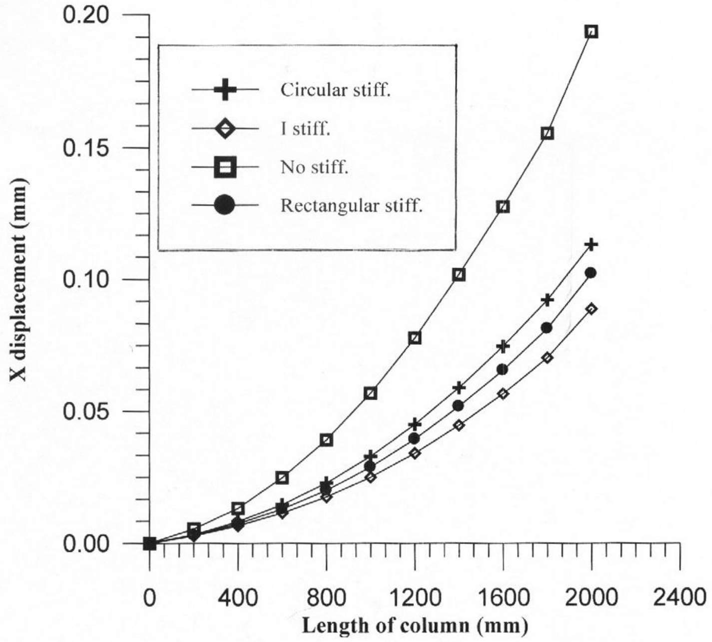
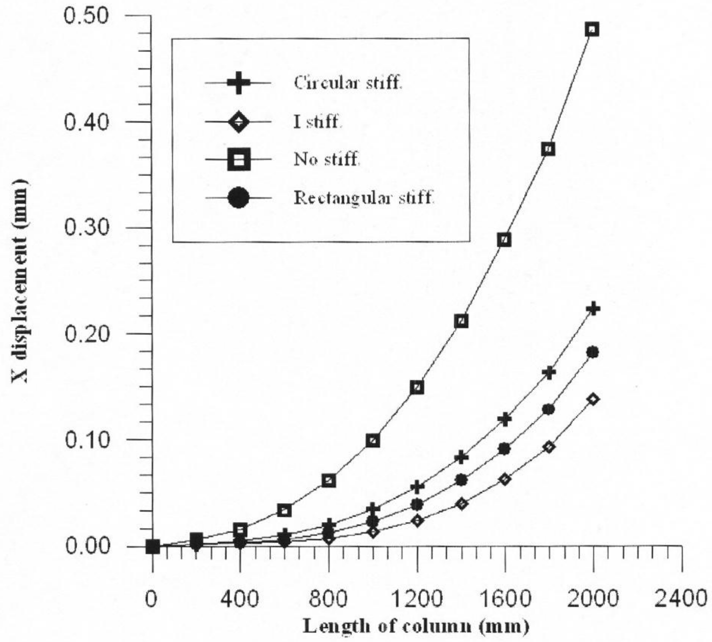


(a)_Bending load



(b)_Torsion load

Fig. 5 : Max. displacement of column with hexagonal cross-section

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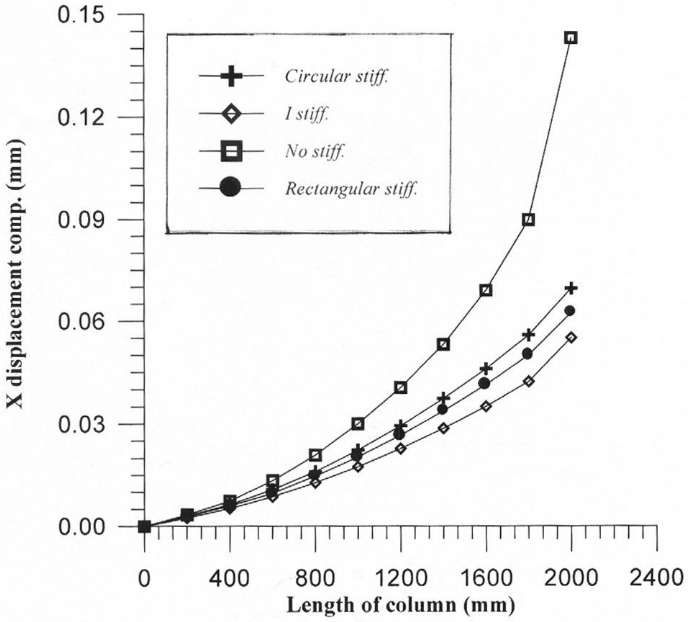
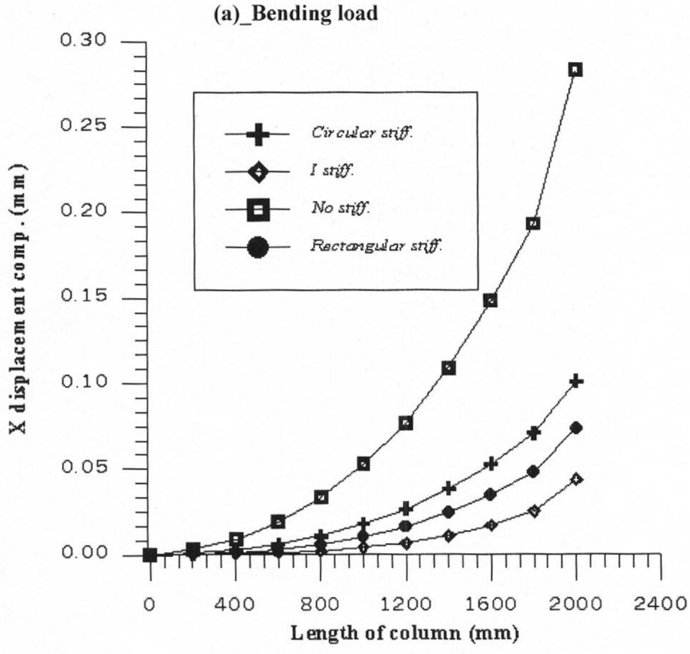


(a)_Bending load



(b)_Torsion load

Fig. 6 : Max. displacement component of acolumn with circular cross-section

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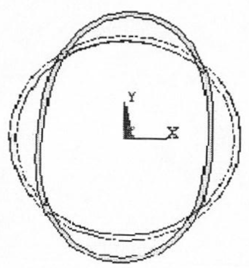
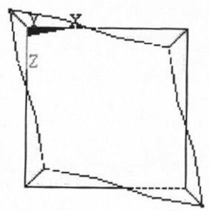
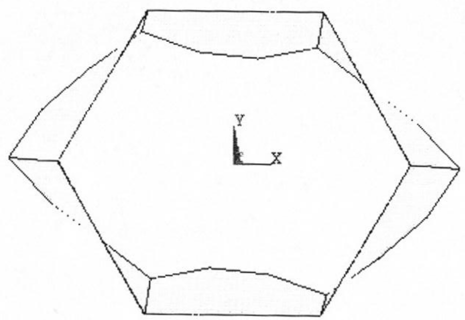


a- First mode of circular cross section column with no stiffeners (ω = 118.88Hz)



b- First mode shape of square cross section column with no stiffeners (ω= 125.67Hz)



c- First mode shape of hexagonal cross section column with no stiffeners (ω= 134.24Hz)

Fig. 7: First mode shape of a column with different cross section area

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NOMENCLATURE:

C_p, C_m=material constant

d=tool diameter(mm)

F_x, F_y=Force components(N)

F_T, F_B=Torsion and bending forces(N)

[K]=Column stiffness matrix (N/mm)

K_p=Coefficient taking into account the effect of point angle.

K_B= Coefficient taking into account the effect of Brinell hardness-number.

[M]=Column mass matrix(g).

M_T,M_B= Torsion and bending moments(Nmm).

S=Feed rate(mm/rev.).

T=Column torque(N .mm).

xm,ym=Exponent of tool diameter while calculating tool torque.

xp, yp= Exponent of tool diameter while calculating tool thrust.

Y=Length of tool(mm).

Z=Length of column(mm).

Ω^2=Column natural frequency(Hz).